Supporting information

Segregation-free bromine-doped perovskite solar cells for IoT applications

Itaru Raifuku[†,‡], Yasuaki Ishikawa[*,†], Yu-Hsien Chiang[‡], Pei-Ying Lin[‡], Ming-Hsien Li[‡], Yukiharu Uraoka[†] and Peter Chen[‡]

[†]Division of Materials Science, Nara Institute of Science and Technology, 8916-5 Takayama, Ikoma, Nara 630-0192, Japan

[‡]Department of Photonics and Hierarchical Green-Energy Materials (Hi-GEM) Research Center, National Cheng Kung University, No. 1, University Rd., Tainan, 701, Taiwan

*Corresponding author: Yasuaki Ishikawa (email: yishikawa@ms.naist.jp)

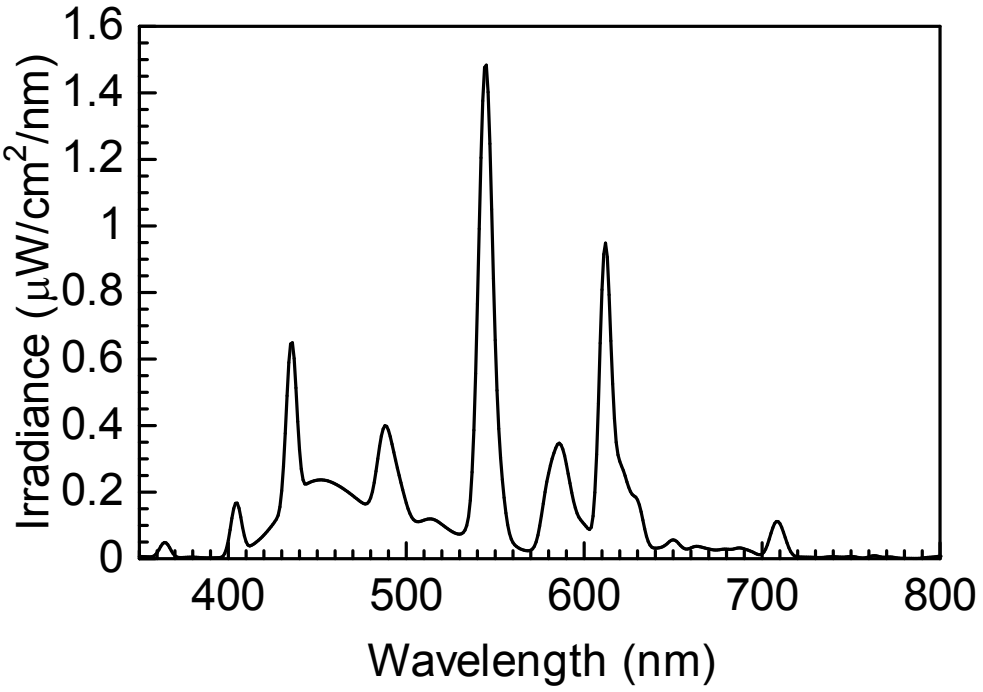

Fig. S1 Emission spectrum of the T5 fluorescent lamp.

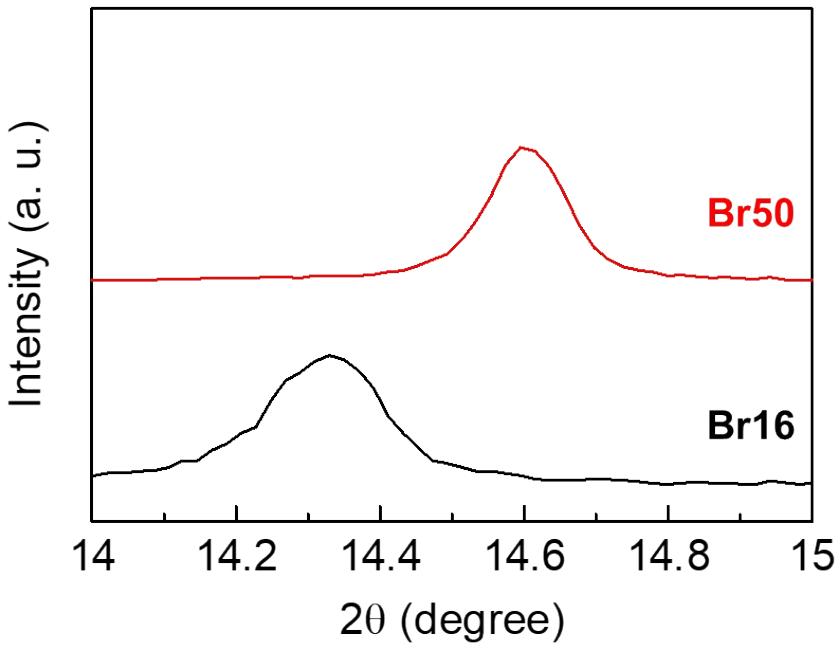

Fig. S2 (110) peak position of 3-cat-Br16 and 3-cat-Br50 perovskite films.

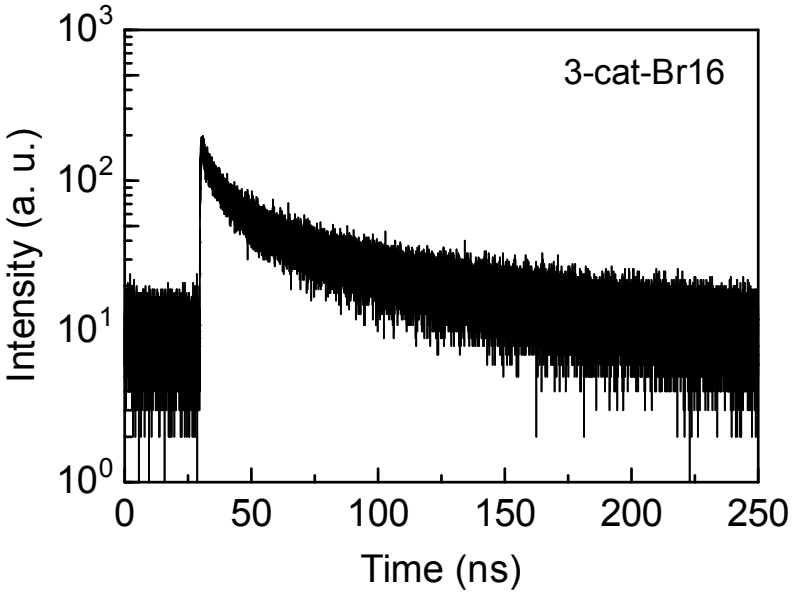

Fig. S3 TRPL spectrum of a 3-cat-Br16 film.

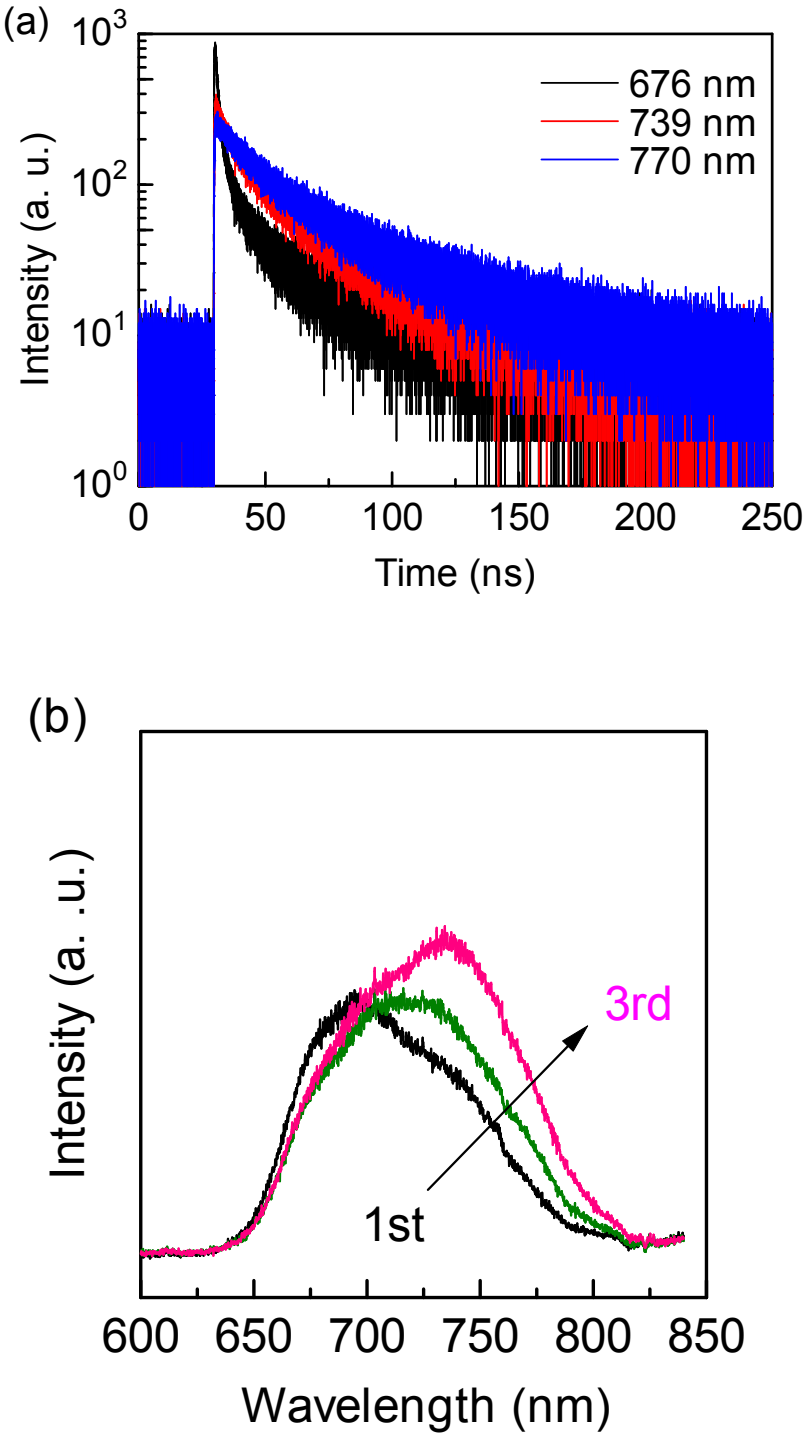

Fig. S4 (a)TRPL spectra of 3-cat-Br50 films with different detection wavelength. (b) PL spectra shift of 3-cat-Br50 films during laser irradiation for TRPL measurements.

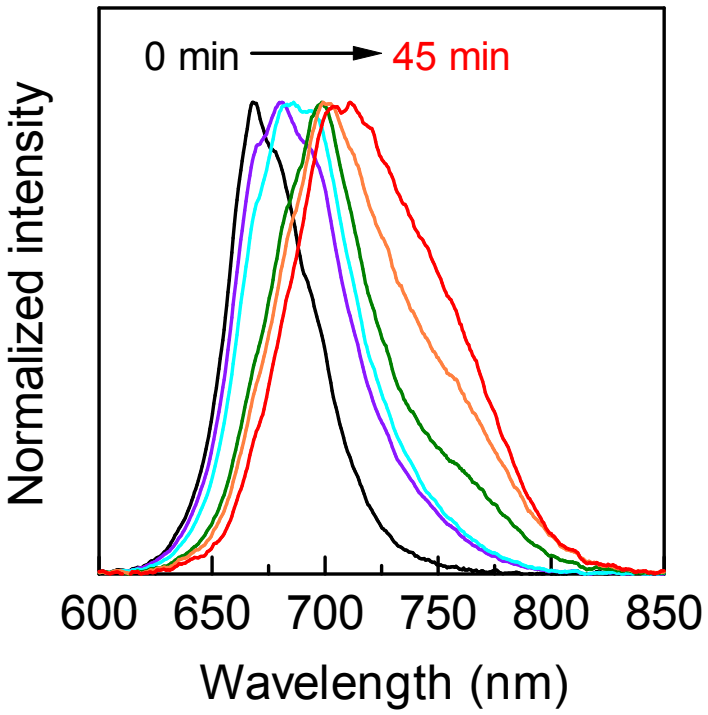

Fig. S5 PL spectra of 3-cat-Br50 films after light soaking (AM1.5G 1 sun) for 0, 5, 10, 20, 30, and 45 min.

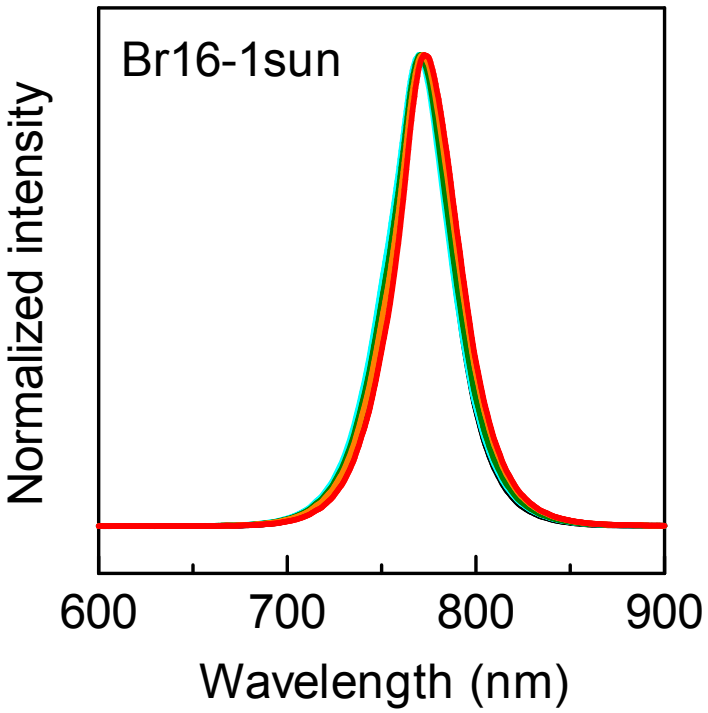

Fig. S6 PL spectra of 3-cat-Br16 films after light soaking (AM1.5G 1 sun) for 0, 5, 10, 20, 30, and 45 min.

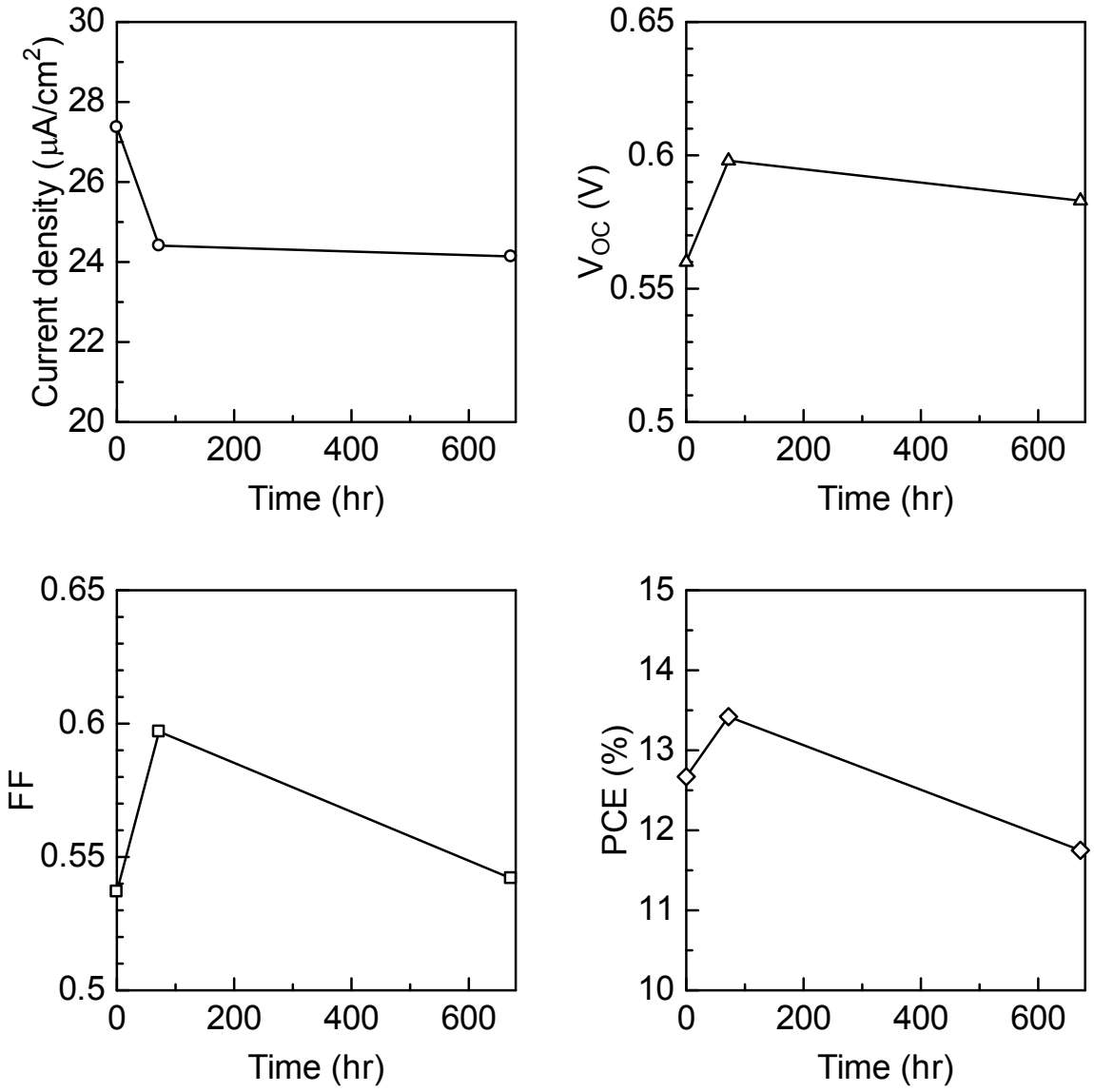

Fig. S7 *J-V* characteristics of 3-cat-Br16 PSCs under 200 lx illumination during stability test. The photovoltaic characteristics were calculated from the forward scan.

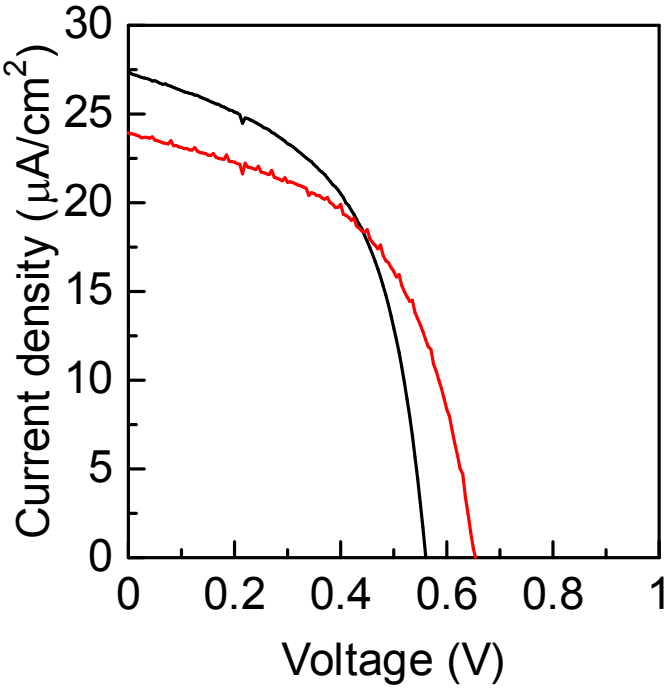

Fig. S8 *J-V* curves of 3-cat-Br16 PSCs stored under ambient condition. The black and red lines represent before storage and after storage for 672 hr, respectively. The *J-V* curves were taken by forward scan.

Table S1. The composition of perovskite precursor solution

	3-cat-Br16	3-cat-Br50
FAI	**93.9 mg**	**98.6 mg**
MAI	**11.3 mg**	**11.9 mg**
PbI_2	**264.5 mg**	**108.9 mg**
$PbBr_2$	**37.2 mg**	**173.4 mg**
CsI (1.3M DMSO solution)	**25 μL**	**25 μL**
DMF	**400 μL**	**400 μL**
DMSO	**100 μL**	**100 μL**

Table S2. Carrier lifetime of 3-cat-Br16 and 3-cat-Br50 films calculated from TRPL spectra. The wavelength in the brackets of 3-cat-Br50 indicate the detection wavelength.

	τ_1 (ns)	τ_2 (ns)
3-cat-Br16	5.41±0.92	33.43±1.69
3-cat-Br50 (676 nm)	2.31±0.21	29.37±1.64
3-cat-Br50 (739 nm)	8.72±0.77	42.12±1.17
3-cat-Br50 (770 nm)	15.15±1.27	58.04±2.22

Table S3. *J–V* characteristics of 3-cat-Br16 PSCs under AM1.5 1 sun condition. Values in the brackets displays *J–V* characteristics of best performed PSCs.

	J_{SC} (mA/cm^2)	V_{OC} (V)	FF	PCE (%)
Forward	**20.35±0.31 (20.72)**	**0.968±0.013 (0.964)**	**0.606±0.011 (0.612)**	**11.9±0.3 (12.2)**
Reverse	**20.68±0.30 (20.99)**	**1.032±0.014 (1.033)**	**0.709±0.010 (0.730)**	**15.1±0.3 (15.8)**

Table S4. *J–V* characteristics of 3-cat-Br50 PSCs under AM1.5 1 sun condition. Values in the brackets displays *J–V* characteristics of best performed PSCs.

	J_{SC} (mA/cm^2)	V_{OC} (V)	FF	PCE (%)
Forward	**14.67±0.39 (15.27)**	**0.963±0.069 (0.952)**	**0.559±0.037 (0.551)**	**7.9±0.9 (8.0)**
Reverse	**14.38±0.68 (15.19)**	**1.018±0.034 (1.026)**	**0.639±0.031 (0.634)**	**9.3±0.4 (9.9)**

Table S5. *J–V* characteristics of 3-cat-Br16 PSCs under 200 lx illumination. Values in the brackets displays *J–V* characteristics of best performed PSCs.

	J_{SC} (μA/cm^2)	V_{OC} (V)	FF	P_{MAX} (μW/cm^2)	PCE (%)
Forward	**27.67±0.52 (28.38)**	**0.680±0.011 (0.685)**	**0.619±0.011 (0.606)**	**11.6±0.4 (11.8)**	**17.9±0.6 (18.1)**
Reverse	**29.84±0.51 (30.53)**	**0.776±0.005 (0.778)**	**0.727±0.009 (0.742)**	**16.9±0.5 (17.6)**	**25.9±0.7 (27.1)**

Table S6. *J–V* characteristics of 3-cat-Br50 PSCs under 200 lx illumination. Values in the brackets displays *J–V* characteristics of best performed PSCs.

	J_{SC} (μA/cm^2)	V_{OC} (V)	FF	P_{MAX} (μW/cm^2)	PCE (%)
Forward	**26.80±1.35 (29.08)**	**0.818±0.057 (0.803)**	**0.527±0.039 (0.471)**	**11.6±1.5 (11.0)**	**17.8±2.2 (16.9)**
Reverse	**29.90±0.96 (31.02)**	**0.812±0.058 (0.815)**	**0.698±0.069 (0.780)**	**17.0±2.5 (19.7)**	**26.1±3.9 (30.3)**

Table S7. Power conversion efficiency of perovskite solar cells under ambient lighting.

Light source	Intensity [lx]	PCE (%)	Device structure	Ref.
LED	200 400	10.8 12.1	PET/ITO/TiO_2/mp-TiO_2/perovskite/Spiro-OMeTAD/Au	[36]
	200 400	12.8 13.3	PET/ITO/SnO_2/mp-TiO_2/perovskite/Spiro-OMeTAD/Au	[37]
	200 400	25.0 26.9	Glass/ITO/SnO_2/MgO/perovskite/Spiro-OMeTAD/Au	[40]
Fluorescent lamp	100 600 1000	22.5 26.4 27.4	Glass/ITO/PEDOT:PSS/perovskite/PCBM/TmPyPB/Ag	[38]
	200 400	24.0 25.4	Glass/ITO/TiO_2/mp-TiO_2/perovskite/Spiro-OMeTAD/Au	[39]
	200	27.1 30.3	Glass/FTO/TiO_2/mp-TiO_2/3-cat-Br16/Spiro-OMeTAD/Au Glass/FTO/TiO_2/mp-TiO_2/3-cat-Br50/Spiro-OMeTAD/Au	This work